AN2530
Application note

Solution for 150 W half bridge resonant DC-DC converter

Introduction

This application note describes a 150 W Half bridge resonant DC-DC converter. This type of SMPS is highly attractive due to its high achievable efficiency, very low noise and compact size.

Resonant converters are among the least common SMPS topologies. There are several reasons why they are not often used, but we will not discuss these reasons in this application note. However, it is worth noting that the resonant topologies have undeniable advantages over the "hard switching" topologies. The very high achievable efficiency of over 90% and up to 95% is very common, as well as their low generated noise due to ZVS (zero voltage switching) and resonant energy transfer.

Other related advantages derived from these converters are their compact size due to their need for smaller power switches (Power MOSFETs usually), smaller transformers, and less generated heat (the lower losses are a part of this). Less heat means a smaller heat sink and a longer life for power components.

If the necessary care is taken in the design phase, the results are very good and the typical issues normally associated with these topologies are avoided.

ST's L6598 half bridge driver has been chosen for this design. Please refer to the L6598 datasheet for full specifications and capabilities, or to other documentation, application notes and books where it is used, in order to have the best picture of this design. All references are provided in *Figure 7*.

This application note concentrates only on the power aspects, because as already mentioned, there are excellent guides for the driver (aside from the datasheet) as well as application notes for SMPS in general, magnetics, topologies, etc.

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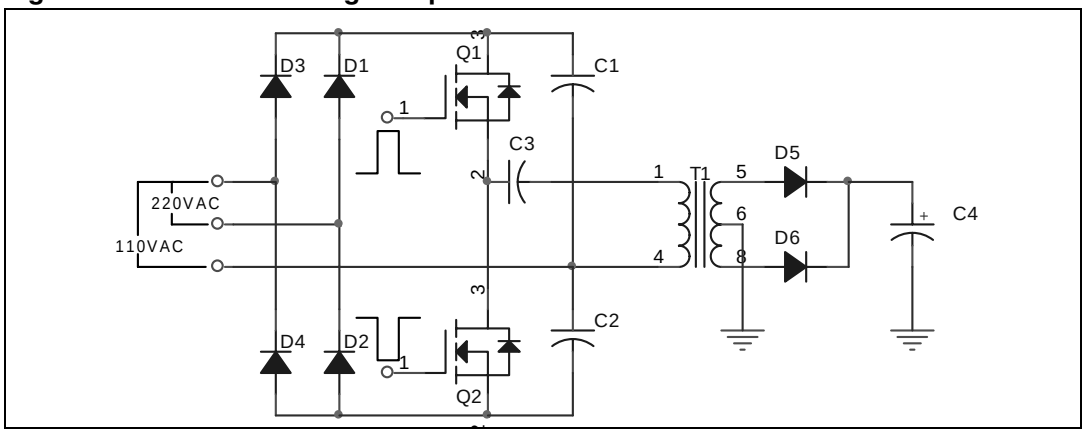
1 Functional overview

The simplest way of describing the functioning of a resonant converter is to compare it with a non-resonant type. Typically a "normal" half bridge transformer is connected to the principal DC bus through a capacitive divider network that creates a "false" ground to feed one of the transformer's ends (*Figure 1*). In this way, the transformer is fed with a voltage that swings (from the transformer's point of view) from zero to negative, negative to zero, zero to positive, then back to zero (therefore repeating the cycle).

The mains DC bus is connected as noted in *Figure 1* for 110 V_{ac} or 220 V_{ac}. The operation is quite straightforward alternating the turn-on of each transistor.

Figure 1. SMPS half bridge simplified schematic



The resonant variation for this type of converter places an "external" inductor to cause a resonance between the capacitive divider network and the external inductor (*Figure 2*), which sums up to the already present leakage inductance of the main transformer.

These components are the ones that require most of the care for this variation of the converter. Nevertheless, remember that every aspect of the design stage has an impact on the overall behavior of the converter.

Figure 2. Resonant SMPS half bridge simplified schematic

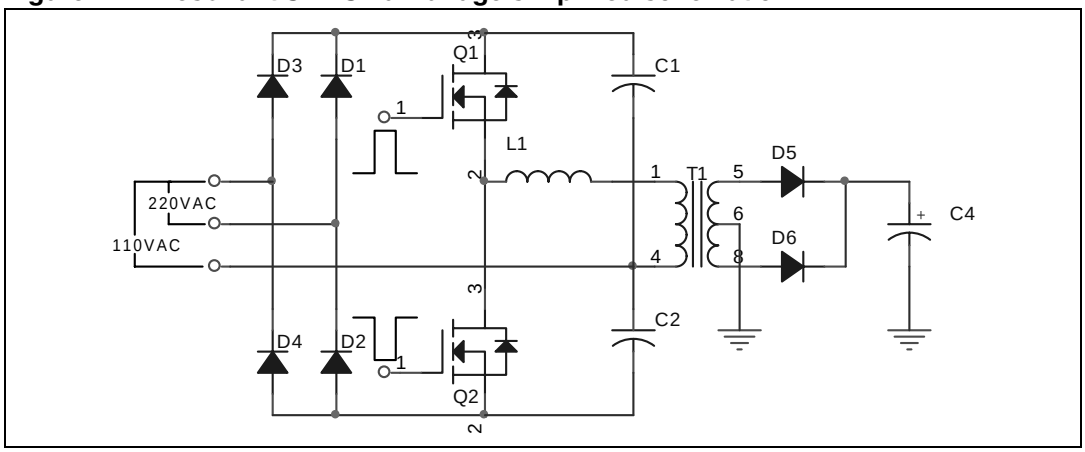


Table 1 gives the BOM (Bill of materials) for this converter. Most of the capacitors do not have an operating voltage, as they operate in low voltage. As for the driver, any voltage

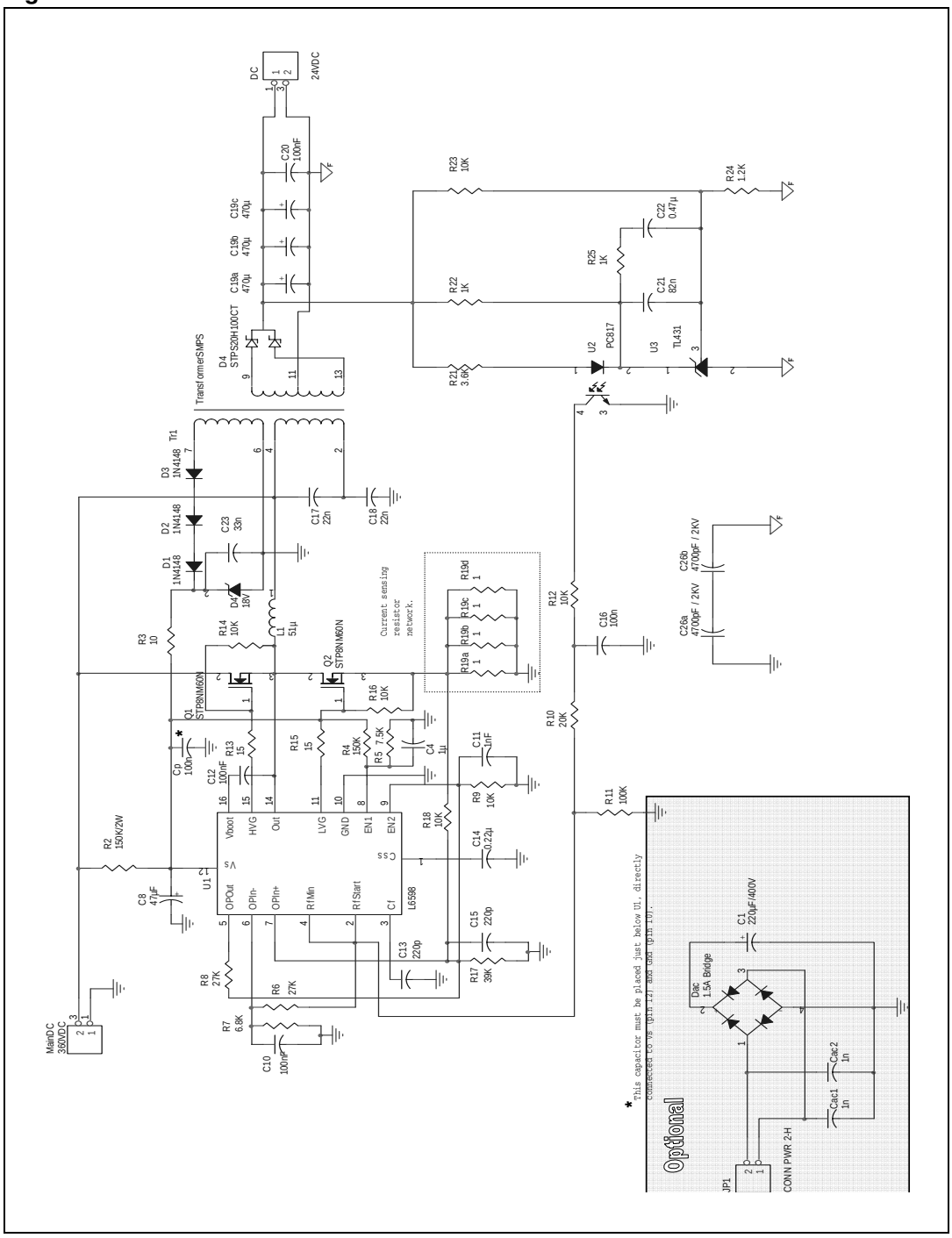
greater than or equal to 16 V is acceptable. The construction details of L1 and Tr1 are discussed later.

Table 1. Bill of materials (BOM)

Qty.	Ref.	Part	Qty.	Ref.	Part	Qty.	Ref.	Part
1	AC	220 V_{ac} Conn.	1	C22	0.47 µ		R16	10 KΩ
2	Cac1	1 nF/400 V	2	C26b	4700 pF / 2 KV		R18	10 KΩ
	Cac2	1 nF/400 V		C26a	4700 pF / 2 KV		R23	10 KΩ
1	C1	220 µF / 400 V	1	DC	24VDC	1	R10	20 KΩ
1	C4	1 µ	1	D1	W08G	1	R11	100 KΩ
1	C8	47 µF	1	D2	STPS20H100CT	2	R13	15
3	C10	100 nF	1	D3	1N4148		R15	15
	C12	100 nF	1	D4	18 V	1	R17	39 KΩ
	C20	100 nF	1	L1	51 µ	4	R19d	1
1	C11	1 nF	2	Q2	STP8NM60N		R19c	1
2	C15	220 p		Q1	STP8NM60N		R19b	1
	C13	220 p	1	R2	150 KΩ/2 W		R19a	1
1	C14	0.22 µ	1	R3	10	1	R21	3.6 KΩ
1	C16	100 n	1	R4	150 KΩ	2	R25	1 KΩ
3	C17	33 n	1	R5	7.5 KΩ		R22	1 KΩ
	C18	33 n	2	R8	27 KΩ	1	R24	1.2 KΩ
	C23	33 n		R6	27 KΩ	1	Tr1	Transformer
3	C19c	470 µ	1	R7	6.8 KΩ	1	U1	L6598
	C19b	470 µ	6	R9	10 KΩ	1	U2	PC817
	C19a	470 µ		R12	10 KΩ	1	U3	TL431
1	C21	82 n		R14	10 KΩ			

Refer to *Figure 3* for the full electrical schematic of this converter.

Figure 3. Converter's full electrical schematic



2 Operational frequencies

Figure 3 shows a gray area with a note "optional". This rectifying stage is not really necessary as it was done for testing and measuring purposes.

More explanations and clarifications are provided as we go through this design.

Much of the basis for this application note was taken from another ST application note, mainly AN1660 (ZVS resonant converter for consumer application using L6598 IC), which is a 180 W ZVS resonant converter. As stated in AN1660 (ZVS resonant converter for consumer application using L6598 IC) you must "choose" some operational parameters that are recalculated after real component values have been chosen. Only your experience with this kind of SMPS can guide you.

For this case the following values have been chosen:

- F_{start} = 300 kHz
- F_{min} = 70 kHz
- F_r = 35 kHz

The frequency values have been chosen keeping in mind that 300 kHz (F_{start}) is quite close to the driver's maximum operational frequency. Therefore, we leave the converter much "room" to change its operational frequency (via the feedback) so the regulation does not suffer because of a range that is too restrictive.

The calculations for Rf_{min} (R11) and Rf_{start} (R6); C_f is C13 (220 pF) in our case, are shown below:

Equation 1

$$Rf_{min} = \frac{1.41}{F_{min} \bullet C_f} = 91.56\ K\Omega (\sim 100\ k\Omega)$$

Equation 2

$$Rf_{start} = \frac{1.41}{(F_{start} - F_{min}) \bullet C_f} = 27.27\ k\Omega\ (\sim 27\ k\Omega)$$

Recalculating F_{min} & F_{start} with actual values of R_{fmin} & Rf_{start}:

Equation 3

$$F_{min} = \frac{1.41}{Rf_{min} \bullet C_f} = 64.09\ kHz$$

Equation 4

$$F_{start} = \frac{1.41}{Rf_{start} \bullet C_f} + F_{min} = 237.4\ kHz$$

3 Transformer and resonant components

In order to avoid the majority of the most difficult problems related to resonant converters, great care must be taken in the design of those components whose primary task is to transfer the energy from the rectified line to the load. These components are the transformer, external inductor, capacitor divider network and the power switches.

Several "methods" and approaches have been taken into account in order to calculate the power transformer and the external inductor (refer to *Section 7: References* at the end of this application note). AN1660 forms the basis for this application note and provides calculations for this objective.

The objective of this application note is to take a closer look at the power stage, so that just the final results for the transformer and the external inductor are shown. However, it is important to notice that the transformer's type (material, size and shape) plays one of the main roles in any converter. For resonants, the coil type is important also.

Table 2 gives transformer and coil data. Litz wires have been used.

3.1 Transformer

- Brand: Epcos
- Type: ETD34
- Material: N67

Table 2. Tr1 Transformer's windings details

Turns		Wires	Wire's diameter [mm]
Primary	50	14	0.2
Secondary	14	38	0.2
Aux.	3	1	0.2

4 Converter's protection schemes, overcurrent, overvoltage

Overcurrent and overvoltage protection features can be added easily thanks to the pins of the L6598 controller. In this section we show how to calculate these values according to the operational parameters chosen.

Again, refer to AN1660 (ZVS resonant converter for consumer application using L6598 IC) or use your own "method" to calculate the peak current. You should expect to be at the maximum at L1 (as well as transformer's primary) and take a safety margin (10% more for example). In this case, the maximum current should be 1.8 A, so we set the maximum current to 2 A.

According to the L6598 datasheet there is a constant voltage of 2 V at pin 2 (Rf_{start}), so this voltage can be used to set the opamp's inverting input (pin 6) to 0.4 V through the R6 & R7 divider network.

The inverting input of internal opamp is set to 0.4 V, so 0.4 V/2 A = 0.2 Ω

A set of 1 Ω/0.25 W resistances was chosen to be readily available and by paralleling them we get 0.25 Ω/1 W, which "generates" 0.25 Ω*2 A = 0.5 V at maximum current.

Then, we have to choose the values for R17 & R18 (a resistor divider network) to get the 0.4 V at Pin 7 (OPin+), R17 = 39 kΩ and R18 = 10 kΩ in our case.

Concerning feedback, regulation is achieved by means of varying the driver's frequency. A heavier load determines a lower operational frequency and the contrary is true for a lighter load. Frequency is changed by varying the current at pin 4 (Rf_{min}). As previously stated, R11 defines the maximum operational frequency and R10, R12 and optocoupler's internal resistance (that varies according to the current supplied to the load) set the actual operating frequency.

5 Full load, normal operation waveforms

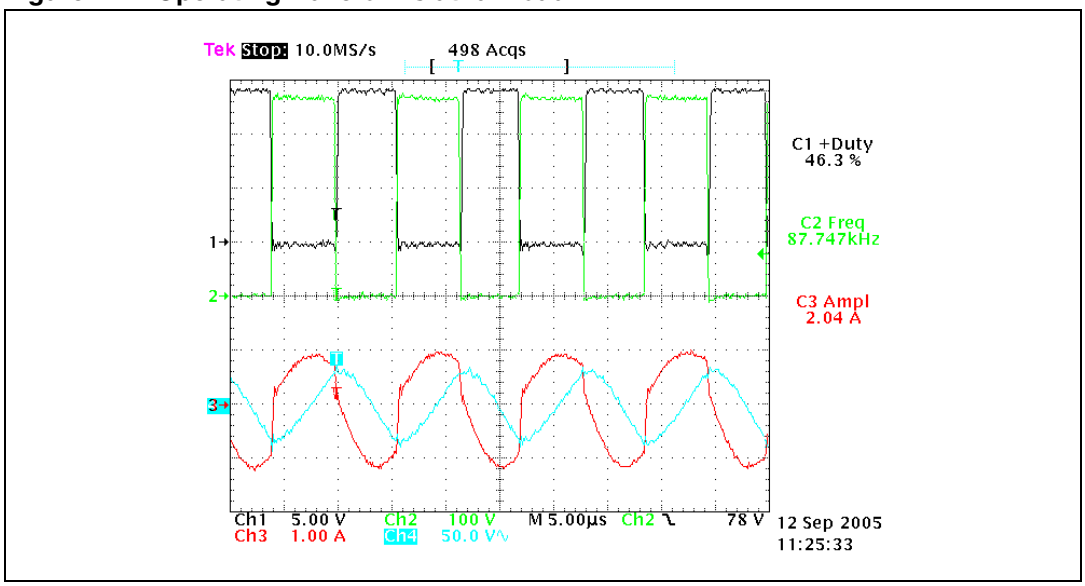
Figure 4 shows the normal full load operation waveforms for this converter.

Channels 1 and 2 are V_g at Q2 and Q1 respectively. Notice that the voltage level at Q1 (upper MOSFET), is up to 370 V due to the charge pump inside the driver.

Channel 3 is the resonant current flowing through L1, measured with a hall effect probe. There is a lack of symmetry probably caused by the hand-wound transformer and coil. The major contributor to this should be the non-symmetric primary winding for the transformer that imposes different loads as current flow changes direction at the primary.

Channel 4 is the resonant voltage at C18.

Figure 4. Operating waveforms at full load



- Measurement conditions
  - Vin = 355 V_{DC} @ DC Main bus
  - Vout = 23.7 V_{DC}, 6.35A (~150 W)

As previously stated in the introduction, this type of converter has some very good characteristics, one of which is the very high efficiency, typically over 90%, that is easily achieved with resonant, very low RF and EMI produced due to ZVS.

Figure 5 shows the efficiency curve against the output power and against input voltage (*Figure 6*). Notice that there are two curves (*Figure 5*), the upper one is the efficiency curve for this converter, as you can see in the schematic in *Figure 3* . The other one is the same converter connected after a PFC circuit. This one uses ST's L4981A as its primary driver, provides 355 V_{DC} and up to 200 W. The application note AN628 appears in *Section 7: References* and is referred to in the conclusion.

Figure 5. Efficiency vs. Pout

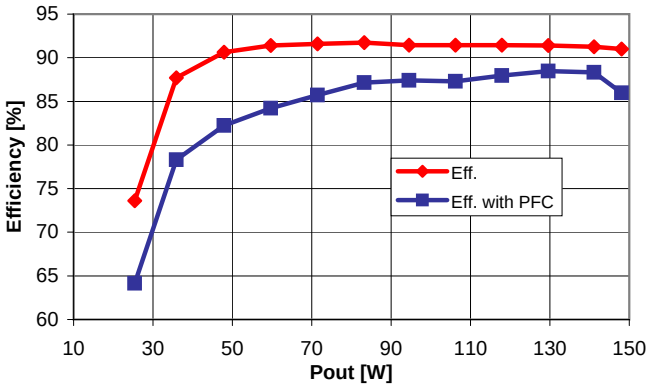


Figure 6. Efficiency vs. Vin

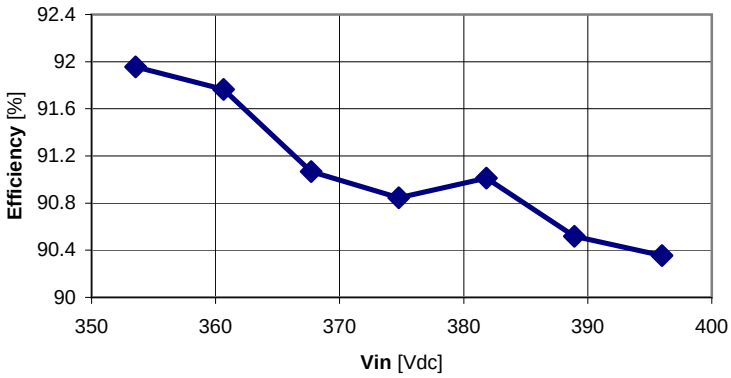


Figure 7. Switching frequency vs output power

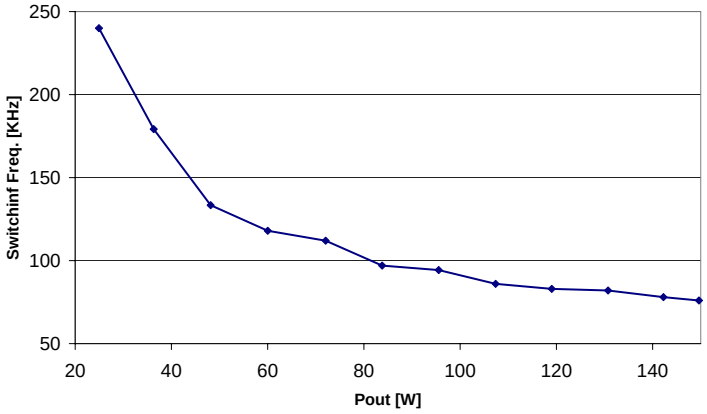
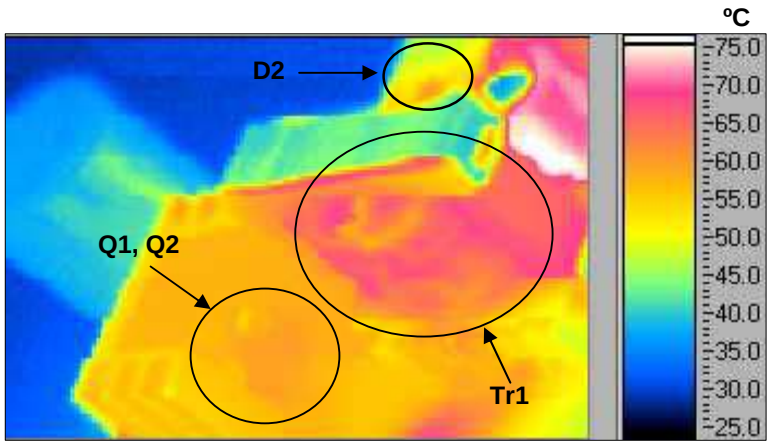


Figure 8. Thermograph



The converter is working at full load in the thermograph in *Figure 8*. Notice that the hottest spot is near the rectifier double diode (D2). The hot lines (white ones) are the dc out filtering capacitors that are being heavily heated by D2 due to the board's position. The transformer is working "cool" as well as the Power MOSFET transistors.

It is important to notice that Q1 and Q2 are working in the 50 ºC range. Originally the board was assembled with bigger transistors, therefore the smaller ones can be used in this application and gain in efficiency (almost 20% gain for light loads). They are easier to drive and cheaper which means that you don't have to "oversize" these (as is usually done in other converter topologies).

6 Conclusion

As already mentioned, a certain degree of attention must be exercised with resonant converters because energy transfer is directly related to this phenomenon. The benefits are substantial and include low emi and rf noise, high efficiency, overall cooler operation, no need for "over sized" power components to prevent failure from spikes, etc., as well as other advantages if designed carefully. As you can see, the load regulation of this one is very good.

It is remarkable that all these measurements and tests have been performed without any forced ventilation. The heatsink provided for the power transistors is very modest, considering the SMPS's power, so it would be easy to avoid any heat sink by designing a suitable copper area for SMD transistors (i.e. DPAK).

The designer will notice that since the power factor for this converter is not good, therefore it is better to connect the converter after a PFC, such as the one with L4981 that has been used to do some of these measurements. It is normal that the power factor is low due to the "spike" nature of this converter's drawn current. If observed with an oscilloscope, a series of spikes can be seen.

7 References

- High frequency switching power supplies, theory & design.
- Closing The Feedback Loop. Lloyd H. Dixon Jr. Unitrode©
- Transformer and inductor design for optimum circuit performance. Lloyd H. Dixon Jr. Unitrode©
- L6598 Datasheet
- AN1673, L6598 off-line controller for resonant converters.
- AN1660, ZVS Resonant converter for consumer application using L6598 IC.
- AN628, Designing a high power factor switching preregulator with the L4981 continuous mode.

8 Revision history

Table 3. Document revision history

Date	Revision	Changes
25-Oct-2007	1	Initial release

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